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Observational Report on the Classical Nova KT Eridani

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Abstract

A report on the spectroscopic and multi-color photometric observations of high galactic latitude classical nova KT Eridani (Nova Eridani 2009) is presented. After 12.2 days from maximum light, broad and prominent emission lines of Balmer series, He I, He II, N II, N III and O I can be seen on the spectra. The FWHM of Hα line yields an expansion velocity of approximately 3400 km s^{-1}. After 279.4 days from maximum light, we can see prominent emission lines of He II and [O III] on the spectrum. Among them, [O III] (4959, 5007) lines show multiple peaks. From the obtained light curve, KT Eri is classified to be a very fast nova, with a decline rate by two magnitude of 6.2 ± 0.3 days and three of 14.3 ± 0.7 days. We tried to estimate the absolute magnitude (M_V) using the Maximum Magnitude versus Rate of Decline relationship and distance of KT Eri. The calculated M_V is approximately -9. Accordingly, the distance and galactic height are approximately 7 kpc and 4 kpc, respectively. Hence, KT Eri is concluded to be located outside of the galactic disk.

Key words: stars: individual (KT Eridani) - novae, spectroscopy, multi-color photometry

1. Introduction

Galactic novae, including both classical and recurrent novae, had been detected along the galactic equator and concentrated strongly to the galactic center (see Warner 2008 for a review). This is due to the possibility of nova eruption which is directly proportional to the number of Population I stars. Figure 1 is a nova map detected by the year of 2010 in galactic coordinates. From this figure, the portion of novae with $|b| > 20°$ is at most about 3%.

Classical novae (CNe, hereafter), discriminated from the recurrent novae (RNe) by their single eruption record, are one category of the cataclysmic variable stars that are close binary system of white dwarf and normal star. This binary property was based on the photoelectric observation and the radial velocity observation by Walker (1954) and Kraft (1958) during DQ Her in its quiescence, respectively. Based on the accumulated light curves, nova classification using the speed class was proposed by Payne-Gaposchkin (1957) and Duerbeck (1981). On the other hand, spectral evolution and classification of CNe had been performed by Williams (1990, 1992).

Nova eruption is caused by the thermonuclear runaway reaction on a surface of the white dwarf (Gallagher & Starrfield 1978 and Starrfield 1989). Mass transfer containing rich hydrogen gas from the secondary star with high temperature and pressure due to the strong surface gravity of the white dwarf leads to thermonuclear runaway.

KT Eridani (Nova Eridani 2009) was detected by a Japanese skillful observer K. Itagaki on 2009 November 25.536 (UT) at 8.1 magnitude (Yamaoka et al. 2009). He reported the position of this object as R.A. $= 4^{\mathrm{h}}47^{\mathrm{m}}54^{\mathrm{s}}.21$, Dec. $= -10°10'43''.1$ (the equinox 2000.0). At first this object had a possibilty of WZ Sge-type dwarf nova because of its smaller rising amplitude than typical novae (by T. Kato in *venet-alert 11692* [1]), but afterwards the star was confirmed to be a nova explosion by spectroscopic observations (Yamaoka et al. 2009). This star is historically the first classical nova ever detected at the constellation of Eridanus. As the location of KT Eri is quite exceptional with high galactic latitude and anti-galactic center ($l = 208°, b = -32°$), this nova is supposed to have something different from ordinary CNe.

Apart from the optical observations, KT Eri was detected at both radio and X–ray (O'Brien et al. 2010, Bode et al. 2010). The radio observations indicate that KT Eri had been detected during its rising stage of the radio light curve. After 55.4 days from maximum light, *Swift* XRT detected a super soft source (SSS). After 65.6 days from the maximum, the SSS was softened drastically.

The main purpose of this paper is to present our optical observational report of classical nova KT Eri from the earliest time to the later stage (more than half a year) of its eruption. In addition we remark the peculiarity of this nova from the point of view of its galactic location. In §2, we present the spectroscopic and multi-color photometric observations. §3 gives results. §4 is for the discussions. Summary is stated in §5.

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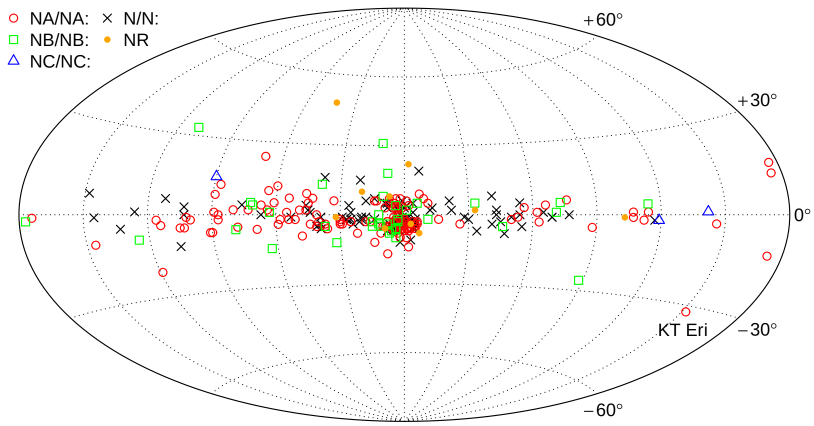

Fig. 1. The distribution of classical and recurrent novae in galactic coordinates (an Aitoff projection) depicted by the present author (KI). The data are from CV catalog (Downes et al. 2005) and IAU circulars (2006-2010 CNe). Red circles, green squares, blue triangles, black crosses and orange filled circles mark are fast novae (NA/NA:), slow novae (NB/NB:), extremely slow novae (NC/NC:), uncategorized novae (N/N:) and recurrent novae (NR), respectively.

Table 1. Instruments of spectroscopy.

Observatory*	Telescope†	R‡	wavelength (Å)
OUS	28cm SCT	400	4200 – 8200
BAO	101cm CCT	1000	4000 – 8000

Note.
*OUS (Okayama Univ. of Sci.), BAO (Bisei Astronomical Observatory).
†SCT (Schmidt-Cassegrain telescope), CCT (Classical Cassegrain Telescope).
‡$R = \lambda/\Delta\lambda$ at 6000 Å.

2. Observations

2.1. Spectroscopy

Our observational systems of spectroscopy are shown in Table 1. The first one, the system of OUS (Okayama Univ. of Sci.) observatory is a combination of DSS-7 (SBIG production) spectrometer and ST-402 (SBIG) CCD camera installed on Celestron 28cm (F/10) Schmidt-Cassegrain telescope. The second system of BAO (Bisei Astronomical Observatory) is a combination of low-resolution spectrometer and DU-440BV (ANDOR) CCD camera installed on 101cm (F/12) Classical Cassegrain Telescope. The spectrometer's resolution ($R = \lambda/\Delta\lambda$) of OUS and BAO is approximately 400 and 1000, respectively. Wavelength calibrations of OUS and BAO were made by Hydrogen–Helium lamp and Iron–Neon lamp, respectively. We have performed the spectroscopic observations from 2009 November 26 to 2010 January 26 at OUS observatory. Additionally, we observed the nova on 2010 August 20 at BAO. The total number of observation is 34 nights. Table 2 is log of spectroscopic observations.

2.2. Multi-color photometry

Our system of multi-color photometry is a combination of ST-7E (SBIG) CCD camera accompanied with B, V, R_c and Strömgren y filter attached to Celestron 23.5cm (F/6.3) Schmidt-Cassegrain telescope. We have performed photometric observations from 2009 November 26 to 2010 March 19 and from 2010 August 5 to December 10 at OUS observatory.

Table 2. Log of spectroscopic observations.

JD*	Date (UT)	Observatory
5162.12	2009 November 26.62	OUS
5164.16	28.66	OUS
5165.21	29.71	OUS
5166.17	30.67	OUS
5167.13	December 1.63	OUS
5168.13	2.63	OUS
5169.13	3.63	OUS
5170.11	4.61	OUS
5172.12	6.62	OUS
5174.11	8.61	OUS
5175.11	9.61	OUS
5183.13	17.63	OUS
5184.07	18.57	OUS
5185.08	19.58	OUS
5186.07	20.57	OUS
5187.12	21.62	OUS
5188.06	22.56	OUS
5195.04	29.54	OUS
5197.03	31.53	OUS
5200.08	2010 January 3.58	OUS
5202.05	5.55	OUS
5203.03	6.53	OUS
5204.02	7.52	OUS
5205.10	8.60	OUS
5209.00	12.50	OUS
5210.04	13.54	OUS
5211.01	14.51	OUS
5213.04	16.54	OUS
5214.00	17.50	OUS
5215.00	18.50	OUS
5220.04	23.54	OUS
5222.01	25.51	OUS
5223.01	26.51	OUS
5429.29	August 20.79	BAO

Note. * JD−2450000.

The total number of observation is 79 nights.

3. Results

3.1. Spectroscopic observations

Figure 2 shows representative spectra of KT Eri at OUS (R~ 400). Broad and prominent emission lines of Balmer series (Hα, Hβ, Hγ), He I (5016, 5876, 6678, 7065), He II (4686), N II (5001, 5679), N III (4640) and O I (7773) are seen on the spectra. Identification of these emission lines is based on those works by Williams (1992) and Williams, Phillips & Hamuy (1994). The FWHM (Full Width at Half Maximum) of Hα line is approximately 3400 km s^{-1} on the first observational night ($+12.2$ days from maximum light; Fig. 2). At first, He II (4686) and N III (4640) lines are blended. Then, after 55 days from maximum light, these lines are split. Moreover He II (4686) become stronger and narrower than before. According to the spectra, this nova is classified as a He/N nova (Williams 1992).

Figure 3 (left) shows the FWHM of Hα's temporal variation. The decline rate of FWHM is ~ 30 km s^{-1} per day and down to 1500 km s^{-1} about 70 days after the maximum light. Figure 3 (right) is a temporal change of Hα profiles. It shows asymmetric profiles at the earlier stages. Such a tendency suggests the existence of the non-spherical expanding gas shell.

Figure 4 is a spectrum of KT Eri in nebular phase at BAO (R$\sim$1000). We can see prominent emission lines of He II (4686) and [O III] (4363, 4959, 5007) on the spectrum. [O III] (4959, 5007) lines show multiple peaks (at least five). These peaks suggest the existence of the multi-ejecta. On the other hand, Hα line seems to be very weak. Such the profile of [O III] is seen in the coronal phase of V444 Sct (Nova Sct 1991; Williams, Phillips & Hamuy 1994). Speed class of V444 Sct is *very fast*. Hence KT Eri seems to have common features of V444 Sct.

3.2. Multi-color photometric observations

Figure 5 is a result of our multi-color (B, V, R_c, y) photometric observations. The data before the discovery are based on archival ones by *Pi of the Sky* [2], *All Sky Automated Survey* [3] (collected by T. Kato in *vsnet-alert 11697* [4]) and Japanese amateur astronomer with Digital Single Lens Reflex camera (Ootsuki et al. 2009; also posted in VSOLJ (Variable Star Observers League in Japan)). From these data, the maximum brightness is supposed to be 5.4 V magnitude. In its early decline phase, the magnitude change shows a rapid fading by 0.32 V magnitude per day. From the derived parameters maximum date t_0 is 2009 November 14.4 ± 0.2 UT (2455149.9 JD). The decline time t_2 and t_3 are 6.2 ± 0.3 days and 14.3 ± 0.7 days, respectively. According to this result, the speed class is thought to be *very fast* ($t_2 < 10$; Payne-Gaposchkin 1957). The statistical relationship between t_2 and t_3 ($t_3 \approx 2.75 t_2^{0.88}$; Warner 1995) agrees well with the observed values.

Figure 6 is our result of the variations of color index ($B-V$ and $V-R_c$). Each color index became bluer. The $B-V$ shows bluest around 2455187 JD (about 37 days from maximum light).

4. Discussions

4.1. Spectral evolution

According to Williams (1992), novae showing stronger lines of He and N have larger expansion velocities and higher level of ionization. Such a type of nova also shows very rapid evolution. Hence the spectral class and speed class of KT Eri is thought to be a He/N nova.

The spectral evolution of KT Eri is similar to that of rapidly evolving CNe or RNe. As mentioned in 3.1, from figure 2 we can see that the blended lines of He II (4686) and N III (4640) are split, and He II narrow line emerges and grows. Such a behavior had been observed in Nova LMC 1990 No. 1 (CN of He/N), V444 Sct (CN of Fe II), V394 CrA (RN of He/N), U Sco (RN of He/N), V745 Sco (RN of He/N) by Williams et al. (1991, 1994) and Sekiguchi et al. (1988, 1989). Sekiguchi et al. (1988, 1989) suggests that He II narrow line in V394 CrA and U Sco during the outburst are attributed to an accretion disc. On the other hand, Diaz et al. (2010) in U Sco during the 2010 outburst proposes the following two ideas: (1) the reionization of circumbinary gas from previous outburst or (2) chromospheric emission from X–ray illumination of the companion by the shrinking nova photosphere. Both X–ray (Super Soft Source) and He II (4686) become strong after around 60 days from maximum light. It is thought that its evolution is correlated with growth of He II (4686), and this phenomenon supports the latter idea of Diaz et al. (2010).

4.2. Distance and galactic location

We have tried to estimate the absolute magnitude at maximum using four Maximum Magnitude versus Rate of Decline (MMRD) relations to derive the distance to KT Eri. The color excess of KT Eri estimated by Ragan et al. (2009) is $E(B-V) \sim 0.08$, which is based on Munari & Zwitter (1997). Table 3 shows the obtained results by using various parameters. Accordingly, the estimated absolute magnitude at maximum is approximately -9. The resultant distance is 6.6 ± 0.8 kpc at weight average.

Using the above results, we can discuss the spatial location of KT Eri. Taking into account that the galactic latitude of KT Eri is -32° and the distance is approximately 7 kpc, its galactic height is 4 kpc. So KT Eri is thought to be outside of the galactic thick disk. If KT Eri is inside the thick disk, the apparent magnitude of maximum becomes brighter than 3 mag. This value seems to be inconsistent with the observations. It was also pointed out by Solar Mass Ejection Imager (Hounsell et al. 2010) that the maximum is about 5 mag.

According to Della Valle et al. (1992) and Della Valle & Livio (1998), typical fast ($t_2 \leq 12$) and He/N novae are concentrated at low height above the galactic plane. Taking account that these novae are located at $z < 100$ pc and are member of Population I star, the location of KT Eri is quite exceptional.

4.3. Absolute magnitude at minimum

The estimated distance and the apparent magnitude of a possible progenitor will give the pre-nova visual absolute magni-

[2] http://grb.fuw.edu.pl/
[3] http://www.astrouw.edu.pl/asas/, Pojmański (2002)
[4] http://ooruri.kusastro.kyoto-u.ac.jp/mailarchive/vsnet-alert/11697

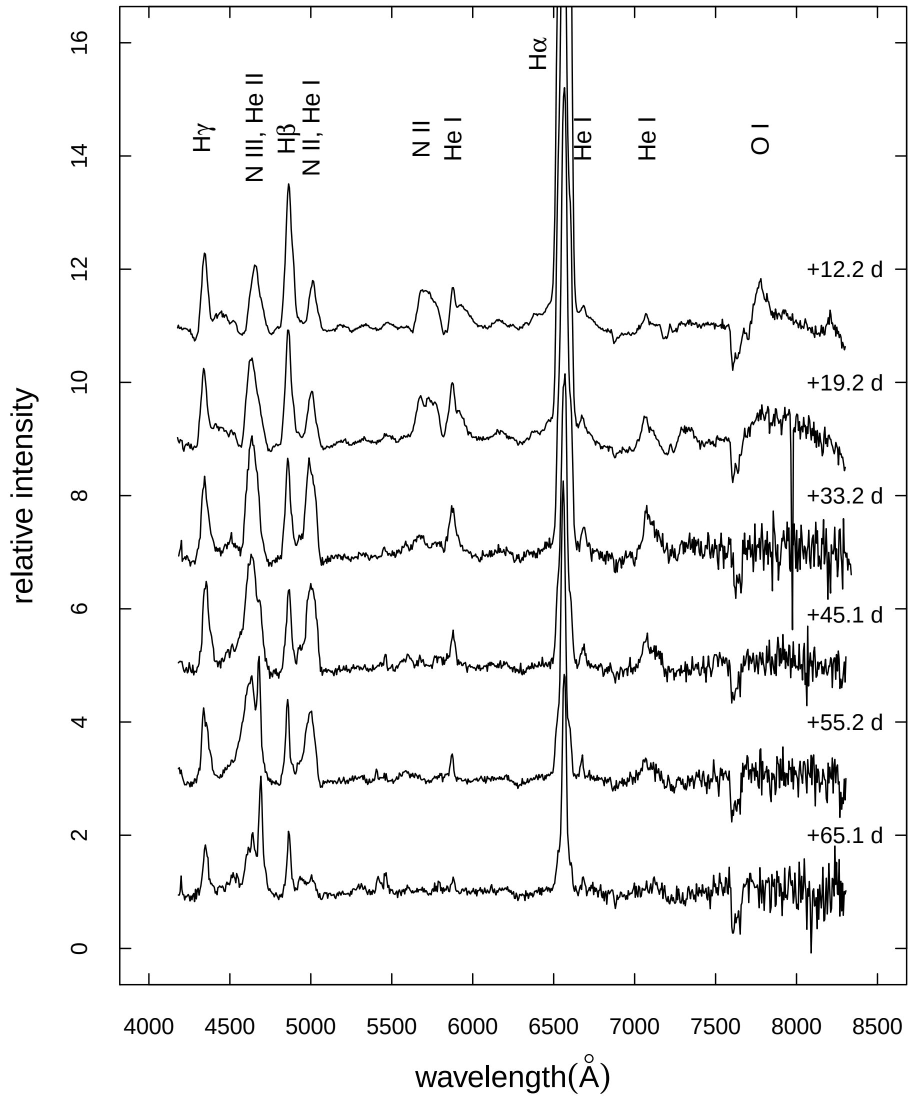

Fig. 2. Our representative spectra of KT Eri. The numerical values on the right edge are the elapsed days from the maximum light. Each of these continuum is normalized as unity. These are obtained at OUS observatory.

Table 3. Absolute magnitude at maximum of KT Eri estimated using MMRD calibrations for t_2.

MMRD	M_V	d (kpc)
Cohen (1988)	-8.79 ± 0.53	6.28 ± 1.55
Capaccioli et al. (1989)	-8.88 ± 0.61	6.55 ± 1.87
Della Valle & Livio (1995)	-8.86 ± 0.41	6.49 ± 1.23
Downes & Duerbeck (2000)	-9.30 ± 0.69	7.94 ± 2.57

Table 4. Comparison of KT Eri with RNe including giant secondary. RNe data from Schaefer (2010).

star	t_2(d)	M_V(max)	M_V(min)
T CrB	4.0	-7.3	0.3
RS Oph	6.8	-10.6	-4.1
V3890 Sgr	6.4	-8.6	-1.2
V745 Sco	6.2	-8.0	1.3
KT Eri	6.2	-9.0	0.4

tude of KT Eri. There exists a star in the Guide Star Catalog at the exact position of KT Eri. If this star (GSC 5325.1837 ~ 14.8 mag) is its true progenitor, its absolute magnitude is approximately 0.4. Taking into account that the absolute magnitude of CNe at minimum is 4.4 (Warner 1987), this result is much brighter by 4 magnitude. It is important to compare KT Eri with RNe. Table 4 shows the properties of RNe and KT Eri. KT Eri has parameters similar to those of RNe. Some of the recurrent nova systems contain giant secondary. Therefore absolute magnitude at minimum is brighter than CNe. If the secondary of KT Eri is a giant, its brightness in quiescence can naturally be explained.

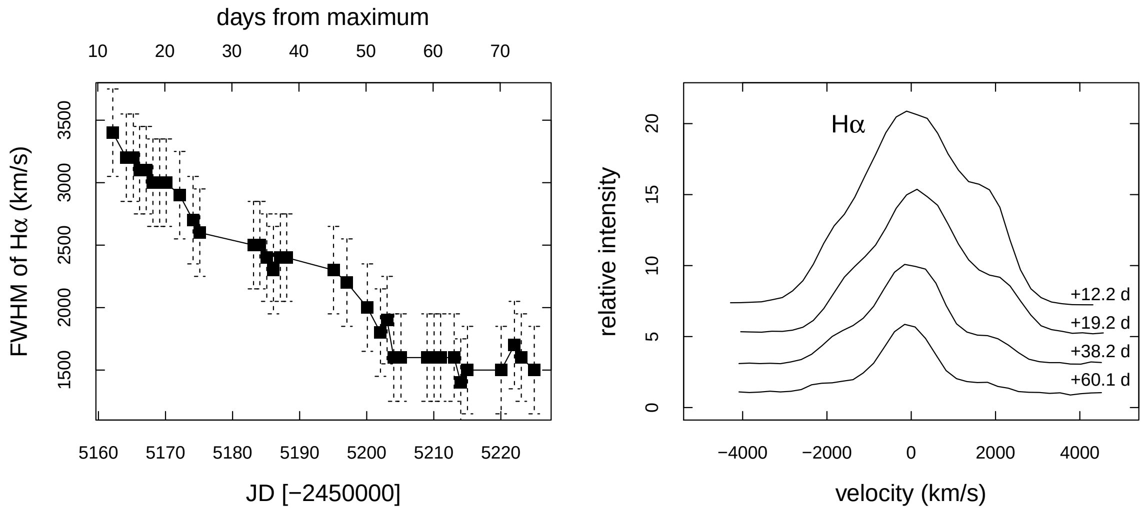

Fig. 3. The left one is the FWHM of Hα's temporal variation. The right one is temporal variation of Hα profiles.

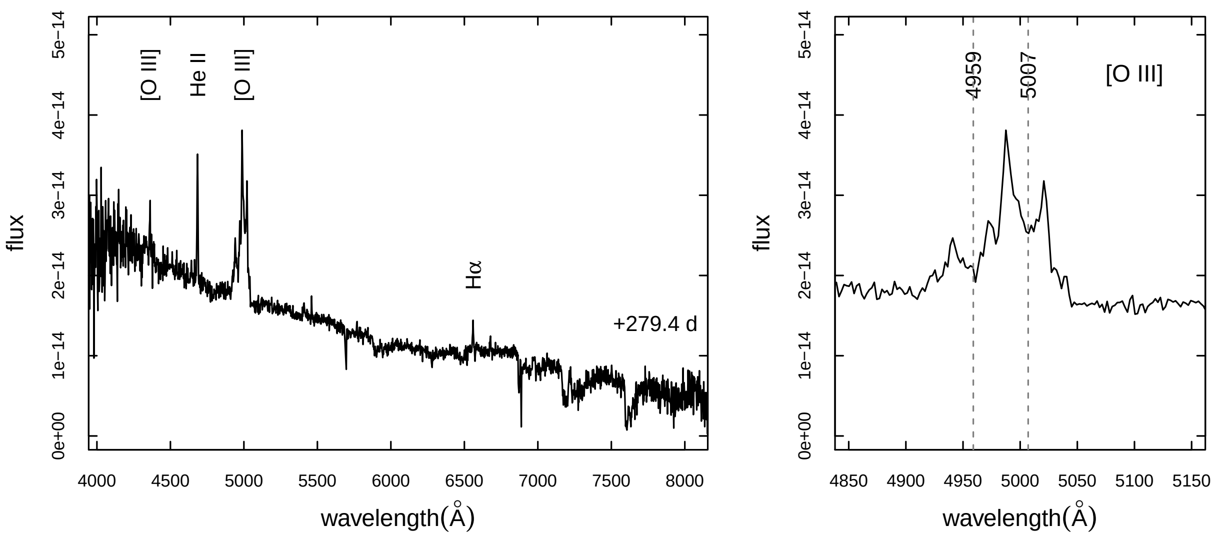

Fig. 4. Spectrum of KT Eri in nebular phase (after 279.4 days from maximum light) at BAO. The right one is enlargement of [O III] (4959, 5007) region. The unit of vertical axis is erg s^{-1} cm^{-2} Å^{-1}.

4.4. 2MASS data at quiescence

We have plotted the color-color diagram of $(J-H)_0$ vs $(H-K_s)_0$ for KT Eri (Table 5) and several RNe (Fig. 7). The other RNe (V394 CrA, CI Aql, IM Nor) are not plotted because there is no data (J, H, K_s) at quiescence. Data of CI Aql and IM Nor by Darnley et al. (2012) give an upper limits. The color of RNe containing M-giant secondary (T CrB, RS Oph, V745 Sco and V3890 Sgr) is comparatively red. On the other hand, the color of KT Eri is bluer which is rather similar to T Pyx and U Sco. It suggests that an evolution of secondary star of KT Eri does not so advanced as RNe with M-giant secondary while this star evolves more than a secondary of T Pyx and U Sco. On the other hand, the periodicity and the quiescence magnitude of KT Eri are suggested that the secondary star is evolved and likely in, or ascending, the Red Giant Branch by Jurdana-Šepić et al. (2012). Our results support their opinion.

Table 5. The progenitor of KT Eri at 2MASS Point Source Catalog. A is the extinction in the J, H and K_s filter which calculated with Cardelli et al. (1989)'s relation as $A_V = 0.2$.

filter	magnitude	A
J	14.62	0.06
H	14.15	0.04
K_s	14.09	0.03

4.5. Recurrency of outbursts

Temporal behavior of KT Eri resembles some of the RNe, for example; V745 Sco and V3890 Sgr (e.g., Williams 1991, Schaefer 2010), but is not similar to T Pyx or IM Nor (e.g., Schaefer 2010, Kato et al. 2002). As is known, RNe are divided into three subclasses (Warner 1995, 2008). From the ob-

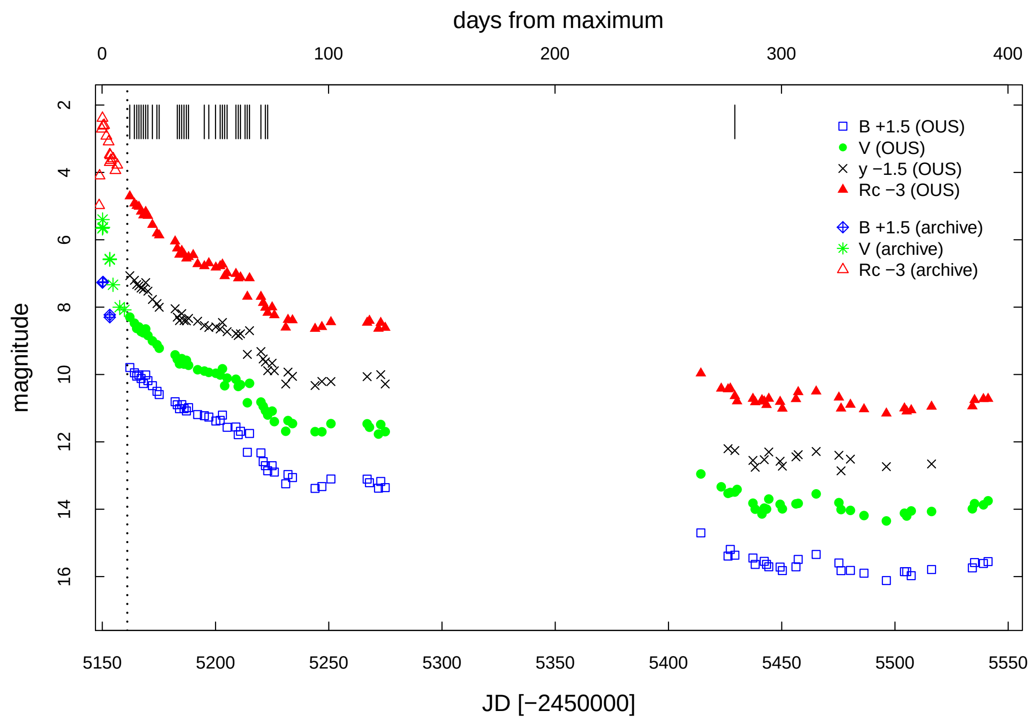

Fig. 5. The result of multi-color photometric observations. The data before the discovery are archival one by ASAS, Pi of the sky and VSOLJ. Dashed line is discovery date. Tick marks indicate the corresponding epochs to the date of our spectroscopic observations.

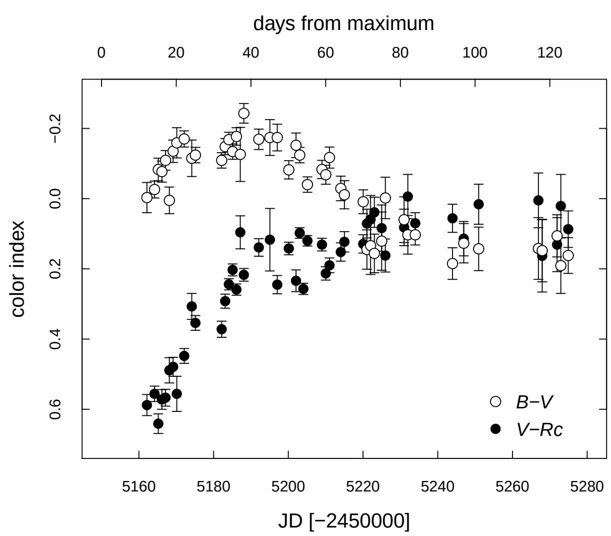

Fig. 6. The result of variations of color index ($B-V$ and $V-R_c$).

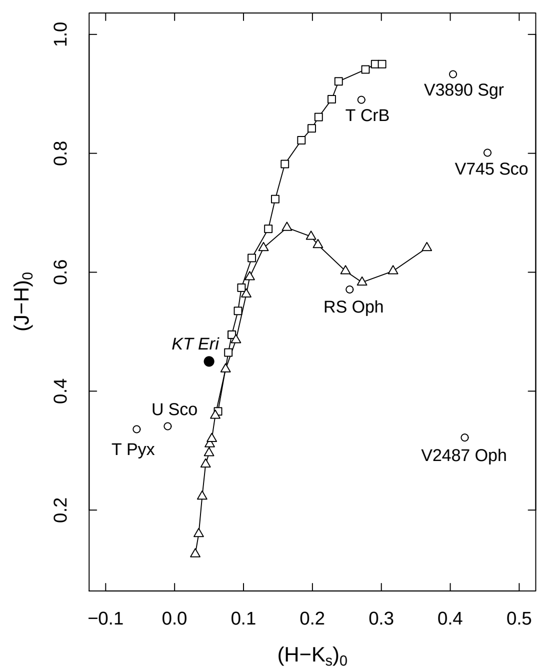

Fig. 7. The color–color diagram of $(J-H)_0$ vs $(H-K_s)_0$. The data of KT Eri, V2487 Oph and RS Oph are from 2MASS Point Source Catalog. These infrared data of U Sco (Hanes 1985), V745 Sco, V3890 Sgr, T CrB and T Pyx (Harrison et al. 1993) are transformed to the system of 2MASS (Carpenter 2001). The lines connecting the squares and triangle are the colors of giant stars from G0 III to M7 III and main sequence stars from F0 V to M6 V, respectively (Bessell & Brett 1988).

tained expansion velocity, KT Eri is thought to have intermediate properties between T CrB subclass and U Sco subclass. From our spectral observations, KT Eri is supposed to be a spectral class of He/N classical nova. However, as is pointed out by Kato, Yamaoka & Kiyota (2004), such a spectral classification does not necessarily exclude the possibility of RN.

On the other hand, RNe have generally a higher accretion rate than CNe due to massive WD (e.g., Hachisu & Kato 1999, 2001a, 2001b, Hachisu et al. 2002; Hellier 2001 for a review).

Table 6. The parameter of KT Eri in this study.

spectral class	He/N
speed class	very fast
t_2	6.2 ± 0.3 d
t_3	14.3 ± 0.7 d
t_0	2009 Nov. 14.4 ± 0.2 UT
m_V(max)	5.4 mag
M_V(max)	~ -9 mag
M_V(min)	~ 0.4 mag
d	~ 7 kpc
z	~ 4 kpc

Applying the WD mass-decline rate relation suggested by Kato & Hachisu (1994) to this case, KT Eri is to have a massive WD. If this is true, KT Eri is considered to be a RN ($T_R > 100$ yr though; see Jurdana-Šepić et al. 2012).

5. Summary

Table 6 summarizes the parameter of this star which are revealed in this study. KT Eri is an exotic nova which appeared on the high galactic latitude and opposite side from galactic center. Spectral class and speed class are He/N and *very fast*, respectively. The distance is approximately 7 kpc and the galactic height $z \sim 4$ kpc. Hence, KT Eri is thought to be located outside of the galactic disk. Accordingly, it is plausible that secondary star is a giant.

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